Chapter

18 DAWN OF MODERN PHYSICS

⇒ As we know that Newtonian Physics is only valid for large object (Macro object) moving with slow speed.

⇒ Newtonian physics is not valid for the object that is extremely small (micro) and moving with extremely high speed.

⇒ The physics which deals with the problems associated with the motion of small object with extremely high speed is called Modern physics.

⇒ It may be also defined as, "the physics after 1890 is called Modern physics".

⇒ Einstein was the father of modern physics.

⇒ "the development in post/Newtonian physics is also known as Modern physics".

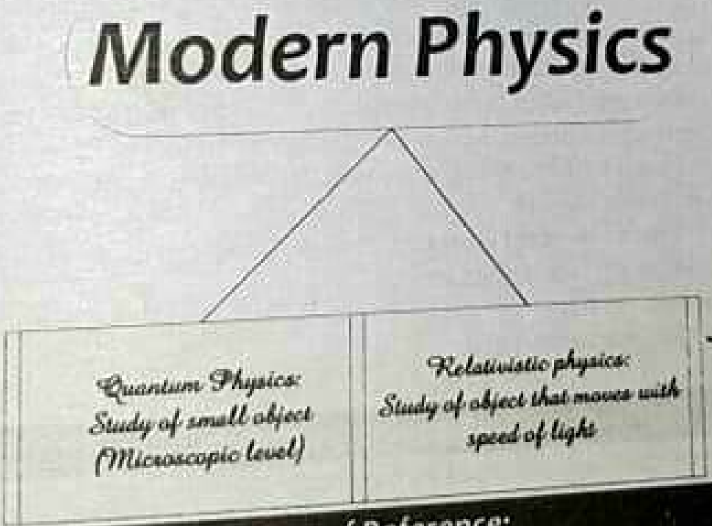
⇒ There is a rule that physicist often use to separate classical physics from quantum. If Planck's constant appears in the equations, it is quantum physics. If it doesn't, it is classical physics.

⇒ here we will discuss mainly two basic theory of Modern physics;

1) Theory of relativity
2) Quantum theory

Post/Newtonian/Old/Classical Physics	Modern physics
1) Valid for macroscopic objects moving with slow speed	1) Valid for Microscopic objects moving with extremely high speed, i.e. Speed of light.
2) Based on Newton law and Maxwell's equation.	2) Based on Einstein theory of relativity and quantum theory.
3) In classical physics, two bombs with identical fuses would explode at the same time.	3) In quantum physics, two absolutely identical radioactive atoms can and generally will explode at very different times.
4) In classical physics; $v \ll c$ $v \rightarrow Relativistic\ speed$ $c \rightarrow Speed\ of\ light \rightarrow 3 \times 10^8 m/sec$	4) In modern Physics; $v \approx c$

⇒ There are two main branches of Physics;



Frame of Reference:

⇒ Physical systems are always observed from some point of view.

⇒ That is, the displacement, velocity, and acceleration of a particle are measured *relative* to some selected origin and coordinate axes.

- ✓ Newton laws of physics has same result in all inertial frame of reference.
- ✓ The speed of light in vacuum is independent of any frame of reference and its value remains constant. (universal constant). It's value in any frame of reference is equal to $3 \times 10^8 m/sec$.

⇒ The Einstein 1st postulate is also called 'Principle of Relativity'.

⇒ If we compare second postulate of Einstein to the classical mechanics (physics) which say 'that speed of light is relative'. Here death of classical mechanics occurs.

⇒ Keep in mind that classical physics is true in its own sense and modern physics (Einstein) in its own. We cannot reject one for another.

Results of Special theory of Relativity

1) Length contraction
2) Time dilation
3) Mass dilation

1) Length Contraction (decrease)

- ✓ The length of the object measured within rest frame of reference is called "Actual/Proper length" denoted by L_o.
- ✓ According to Einstein if we have rod, first we measure its length when it was in rest frame - say it L_o, again if we measure its length when it starts motion along its length there will occur decrease or contraction in its length, new length is 'L'.

$$Here\ L_o > L$$

- ✓ As;

$$v < c \Rightarrow \frac{v}{c} < 1 \Rightarrow 1 - \frac{v^2}{c^2} < 1 \Rightarrow \sqrt{1 - \frac{v^2}{c^2}} < 1$$

So;

$$L = \frac{L_o}{\gamma} \quad \therefore L_o \text{ is gamma time greater then } L$$

$$L = \sqrt{1 - \frac{v^2}{c^2}}\, L_o \quad \because \sqrt{1 - \frac{v^2}{c^2}} < 1$$

- ✓ Note that if the rod moves along its diameter or perpendicular to length then its length will not decrease but its diameter will be decreases.
- ✓ If the event and observer are in different frame of reference then there will be no change in length feel by observer.
- ✓ If the event and observer are in same frame of reference then there will change in length feel by observer. in this case length of the rod will be;

$$L = L_o$$

2) Time dilation:

- ✓ The Time noted for an object within rest frame of reference is called "Actual/Proper Time" denoted by T_o
- ✓ When observer at different frame of reference are in a relative motion, they will always judge the new time 'T' longer.

$$T > T_o$$

- ✓ According to Einstein time is not absolute but it is relative (if single event is studied in two different frames of reference then the time noted from the two frames of reference will be not same).
- ✓ As;

$$T > T_o$$

$$v < c \Rightarrow \frac{v}{c} < 1 \Rightarrow 1 - \frac{v^2}{c^2} < 1 \Rightarrow \sqrt{1 - \frac{v^2}{c^2}} < 1 \Rightarrow \frac{1}{\sqrt{1 - \frac{v^2}{c^2}}} > 1$$

So;

$$T = \gamma T_o$$

$$T = \frac{T_o}{\sqrt{1 - \frac{v^2}{c^2}}}$$

- ✓ ***What about the clocks? How they will be able to show/Measure the Increase in mass?***

⇒ Non-accelerated frame of reference is called Inertial frame of reference. ($v = constant, \Delta v = 0, a = 0$)

⇒ If a different origin and/or set of axes is used, then different numerical values are obtained for $\vec{r}$, $\vec{v}$ and $\vec{a}$, even though the physical event is the same.

⇒ An **event** is a physical phenomenon which occurs at a specified point in space and time.

⇒ There are two types of Frame of Reference;

1) Inertial Frame of Reference

⇒ An inertial frame is one in which Newton's "Laws" of Motion are valid.

⇒ Moreover, any frame moving with constant velocity with respect to an inertial frame is also an inertial frame of reference.

⇒ While $\vec{r}$ and $\vec{v}$ would have different numerical values as measured in the two frames $\vec{F} = m\vec{a}$, in both frames.

⇒ ***Newtonian relativity***

Quote: The Laws of Mechanics are the same in all inertial reference frames. What does "the same" mean? It means that the equations and formulae have identical forms, while the numerical values of the variables may differ between two inertial frames.

⇒ ***Fundamental frame***

It follows that there is no preferred frame of reference—none is more fundamental than another.

2) Non-Inertial Frame of Reference:

⇒ Accelerated frame of reference is called Non-Inertial frame of reference.

⇒ For non-inertial frame of reference, $a \neq 0$.

⇒ In non-inertial frame of reference gives different results. (i.e. Newton's laws are not valid in this frame of reference).

⇒ This frame of reference derived from Newton's first law. (i.e. Law of Inertia).

⇒ Here we will study about different aspects of Non-inertial frame of reference.

⇒ Earth is considered to be Non-inertial frame of reference.

⇒ The motion of accelerated car/bus/train etc. is also Non-inertial frame of reference.

Transformation

- The conversion of one frame of reference into another frame of reference is called Transformation.

Some useful concept and definitions

⇒ ***Relative motion:*** A motion that is not fixed or not constant.

⇒ ***Absolute motion:*** A motion that is fixed or constant.

⇒ Rest and Motion are relative not absolute, because they depend upon frame of reference.

⇒ An agent that depends upon frame of reference will be relative w-r-t to each other.

⇒ According to Newton and Galileo Time is absolute (it is independent of Reference that is x-y-z).

⇒ According to Einstein time does not depends upon frame of reference, (time is not absolute neither it is relative) but he added it to frame of reference axis, "he says that along with x-y-z reference axis there is another reference axis called time.

⇒ So, according to Einstein there are 4 Parameter, (X-Y-Z and Time).

⇒ According to classical physics is absolute.

⇒ According to modern physics;

Length, Time and mass are relative.

Einstein theory of Relativity

There are two theories of relativity, presented by Einstein;

1) Special theory of Relativity
2) General theory of Relativity (Relativity of simultaneity)

Einstein special theory of Relativity

⇒ Einstein special theory of relativity is based on Inertial frame of reference.

⇒ ***There are two postulates of this theory;***

Note that Clock will tick slow in moving frame of reference because of the reason that Time and other activities also dilated.

✓ MCQS POINTS:

- In moving car if a person thrown a ball upward, inside the observer will see that the ball is at rest (it moving along the train) i.e. the observer will receive the ball perpendicular in its hand.
- But the observer outside observing this event, according to him the motion of the ball will be parabolic and the ball according to him will cover some distance behind the car.
- So, the time observed (by observer) for a single ball (single event) is different, this difference is created by the distance, which the two observer notes different.

3) Mass Dilation/Increase:

- ✓ According to Einstein the mass is also relative.
- ✓ You have note that if we weigh the bullet of riffle its mass is approximately 100-200 g but if it is fired it can directly enter in human body and its mass feels by the human when he is hurts is too much. Here in this situation this consequence of theory relativity applicable.
- ✓ This is true for all object if the objects are moving with speed of light then there will be some increase in its mass.
- ✓ The main reason behind this is, "As we know that Matter is condensed form of energy", so in high speed some energy is converted into mass due to which mass dilation can be feels. This is based on this equation; $E = mc^2$.
- ✓ When observer at different frame of reference are in a relative motion, they will always judge the new Mass 'M' longer.

$$M > M_o$$

- ✓ As:

$$M > M_o$$

$$v < c \Rightarrow \frac{v}{c} < 1 \Rightarrow 1 - \frac{v^2}{c^2} < 1 \Rightarrow \quad 1 - \frac{v^2}{c^2} < 1 \Rightarrow \frac{1}{\sqrt{1 - \frac{v^2}{c^2}}} > 1$$

So:

$$M = \gamma M_o$$

$$M = \frac{M_o}{\sqrt{1 - \frac{v^2}{c^2}}}$$

- ✓ The factor speed (speed of light) is responsible for mass increase.

What is time Travel?

Time travel is the concept of movement between certain points in time, analogous to movement between different points in space by an object or a person, typically using a hypothetical device known as a time machine. Time travel is a widely-recognized concept in philosophy and fiction. The idea of a time machine was popularized by H. G. Wells' 1895 novel The Time Machine.

Through time machine the time travel between past and future is possible. One can see their future and past in time machine.

Most of the scientist are working on this, "several attempts have been made by scientists to make time machine".

Note that the solution of concept of time machine can be found in theory of relativity consequence that is time dilation.

Some Important Discussions:

> in reality:

$$c \gg v$$

$$\because \frac{v}{c} \ll 1 \Rightarrow \frac{v^2}{c^2} \ll 1 \Rightarrow \frac{v^2}{c^2} \Rightarrow 0$$

So, $1-\frac{v^2}{c^2}=1$ *so for normal speed/In reality;*

$$T = T_o, \quad L = L_o, \quad M = M_o$$

➤ if $v = c$ (practically not possible);

For this case;

$$\frac{v}{c}=1 \Rightarrow \frac{v^2}{c^2}=1 \Rightarrow 1-\frac{v^2}{c^2}=1-1=0$$

$$T \propto \frac{1}{\sqrt{1-\frac{v^2}{c^2}}} \text{ and } M = \frac{M_o}{\sqrt{1-\frac{v^2}{c^2}}} \text{ and } t = \infty$$

➤ if $c = \infty$;

So;

$$\frac{v^2}{c^2}=\frac{v^2}{\infty}=0$$

$$1-0=1$$

$$1-\frac{v^2}{c^2}=1 \text{ then,}$$

$$M = M_o, T = T_o, L = L_o$$

➤ when event and observer both are in single frame of reference; then;

$$M = M_o, \ T = T_o, \ L = L_o$$

Thermal/Hot Body Radiation

- ✓ we are familiar about the concept if we increase the temperature of an object then some rays are emitted from that body which is actually called thermal radiation.
- ✓ So, everybody emits heat radiations at all finite temperature (Except 0 K) as well as it absorbs radiations from the surroundings. Exchange of energy along various bodies takes place via radiation.
- ✓ Thermal radiation depends upon temperature and nature of conductor.
- ✓ Some cases;

1) $if\ T_{system} > T_{surrounding}$ then;

$$Emission\ of\ radiation > Absorption$$
$$Intensity\ of\ emission > Absorption$$

2) $if\ T_{system} < T_{surrounding}$ then;

$$Emission\ of\ radiation < Absorption$$
$$Intensity\ of\ emission < Absorption$$

3) $if\ T_{system} = T_{surrounding}$ then;

$$Absorption = Emission$$

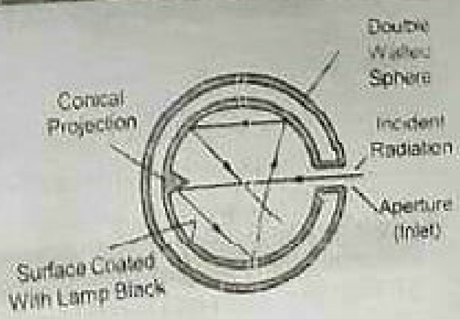
In this case the body is said to be thermally stable body.

Black Body

⇒ The term black body was introduced by Gustav Kirchhoff in 1860.

⇒ A black body is an ideal body that can absorb or emit all kinds of radiation. (100% absorber and emitter) all kinds of radiation.

⇒ If a body absorbs all of radiation it will appears to be black.



⇒ Black-body radiation is also called thermal radiation, cavity radiation, complete radiation or temperature radiation.

⇒ Black holes are near-perfect black bodies, in the sense that they absorb all the radiation that falls on them. It has been proposed that they emit black-body radiation (called Hawking radiation), with a temperature that depends on the mass of the black hole.

⇒ The thermal radiation spontaneously emitted by many ordinary objects can be approximated as black-body radiation. A perfectly insulated enclosure that is in thermal equilibrium internally contains black-body radiation and will emit it through a hole made in its wall, provided the hole is small enough to have negligible effect upon the equilibrium.

⇒ Most of the energy radiates by Black body is infra-red and cannot be perceived by the human eye.

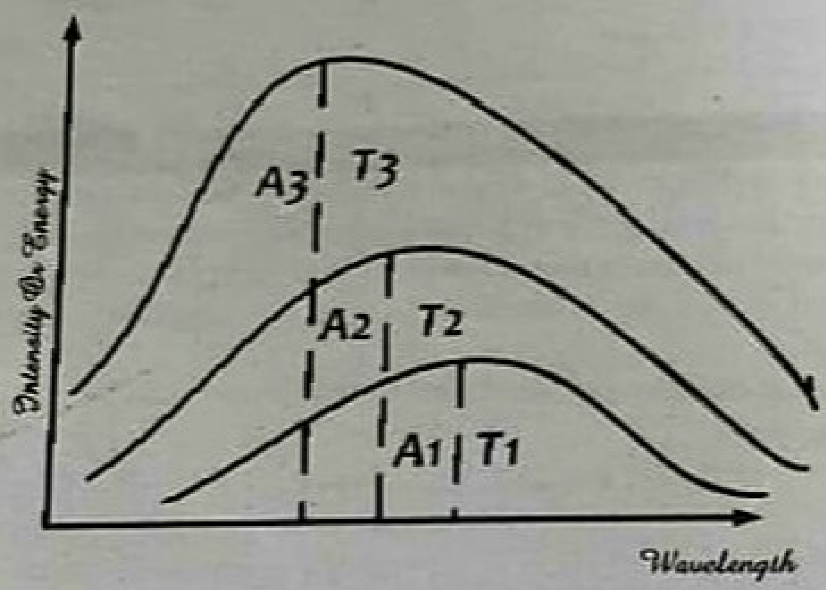
⇒ Although planets and stars are neither in thermal equilibrium with their surroundings nor perfect black bodies, black-body radiation is used as a first approximation for the energy they emit.

Spectrum of Black Body

✓ Black-body radiation has a continuous spectrum that depends only on the body's temperature.

✓ The radiation or emitted or absorb by black body, spectrum of these radiations is known as black body radiation spectrum.

✓ Some experimental observations from black body radiation spectrum:



✓ We are familiar that;

$$Temperature \propto Area\ enclosed \propto No\ of\ \lambda\ emitted$$

✓ The above spectrum shows that;

$$T_3 > T_2 > T_1$$
$$\lambda_3 < \lambda_2 < \lambda_1$$
$$E_3 > E_2 > E_1$$
$$I_3 > I_2 > I_1$$

✓ Intensity and energy can be related by the following relation;

$$I = \frac{E}{A.t}$$

✓ ***Some important points regarding this graph:***

- The shape of this graph is same at any temperature.
- The peak value is different at different temperature.

Wein Displacement Law

⇒ The maximum wavelength is inversely proportional to the absolute temperature of the radiator.

$$\lambda_{maximum} \propto \frac{1}{Temperature} \Rightarrow \lambda_m = \frac{Constant}{T}$$

This can be also written as;

$$T\lambda_m = Constant$$

The product of wavelength at which intensity is maximum and temperature of that material is always constant.

⇒ ***What is the technique used for finding temperature of Stars?***

By using this law, we can guess the temperature of the stars. "By knowing the wavelength of the radiation emitted by stars

Stefan's law

⇒ According to it the radiant energy emitted by a perfectly black body per unit area per sec (i.e. emissive power of black body) is directly proportional to the fourth power of its absolute temperature, i.e.

$$E \propto T^4 \Rightarrow E = constant\ T^4 \Rightarrow E = \sigma T^4$$

⇒ where $\sigma(Sigma)$ is a constant called Stefan's constant;

⇒ The value of $\sigma = 5.67 \times 10^{-8}\ W/m^2K^4$

⇒ **(i) For ordinary body:** $e = \sigma E = \epsilon\sigma T^4$

⇒ **(ii) Radiant energy:** If Q is the total energy radiated by the ordinary body then:

$$e = \frac{Q}{A \times t} = \epsilon\sigma T^4 = A\epsilon\sigma T^4 t$$

⇒ **(iii) Radiant power (P):** It is defined as energy radiated per unit area i.e.

$$P = \frac{Q}{t} = A\epsilon\sigma T^4$$

⇒ If an ordinary body at temperature T is surrounded by a body at temperature T_0, then Stefan's law may be put as;

$$e = \epsilon\sigma = (T^4 - T_0^4)$$

Total emittance or total emissive power (e): It is defined as the total amount of thermal energy emitted per unit time, per unit area of the body for all possible wavelengths.

Emissivity (ϵ): Emissivity of a body at a given temperature is defined as the ratio of the total emissive power of the body (e) to the total emissive power of a perfect black body (E) at that temperature i.e.

$$\epsilon = \frac{e}{E}$$

(i) For perfectly black body ϵ = 1

(ii) For highly polished body ϵ = 0

(iii) But for practical bodies emissivity (ϵ) lies between zero and one ($0 < \epsilon < 1$).

Classical Physics about Black Body radiation

⇒ Classical physics fails to explains Black body radiation because According to classical physics the light will be absorbed or emitted only in continuous form. Not in discrete.

QUANTUM THEORY OF RADIATION/Plank's Radiation Law

⇒ The wave theory successfully explains many properties of electromagnetic radiations such as reflection, refraction, diffraction, interference, polarization, etc., but fails to explain some phenomena like black body radiation, photoelectric effect, etc.

⇒ In order to explain black body radiation and photoelectric effect, Max Planck in 1901 presented a new theory which is known as quantum theory of radiation.

⇒ According to this theory, a hot body emits radiant energy not continuously but discontinuously in the form of small packets of energy called quantum (in plural quanta). The energy associated with each quantum of a given radiation is proportional to the frequency of the emitted radiation.

$$E \propto \nu\ \ Or\ E = h\nu$$

⇒ where, h is a constant known as Planck's constant. Its numerical value is 6.624×10^{-27} erg-sec.

⇒ The energy emitted or absorbed by a body can be either one quantum or any whole number multiple of $h\nu$, *i. e.*, $2h\nu, 3h\nu, 4h\nu, \ldots, nh\nu$ quanta of energy.

⇒ Thus, energy emitted or ,absorbed = $nh\nu$, where n can have values 1, 2, 3,4, ... Thus, the energy emitted or absorbed is quantized.

Photon

In 1905; Einstein pointed out that light can be supposed to consist of a stream of particles, called photons. The energy of each photon of light depends on the frequency of the light, I. e., $E = h\nu$. Energy is also related according to Einstein, as $E = mc^2$ where m is the mass ofphoton. Thus, it was pointed out that light has wave as well as particle characteristics (dual nature).

Energy of photon	Energy of photons is denoted by $E = h\nu$, where h is Planck constant, ν is the frequency of photons, and E is the energy of photons.
Velocity of photon	The velocity of photons and the velocity of light are equal (c). Therefore, $c = \nu\lambda$ Here, λ is the wavelength of wave connected to photon $\therefore E = h\nu = hc/\lambda$
Mass of photon	The mass of photons at rest is zero but it will be non-zero if the photons are moving. Assuming m to be the effective mass of photons, energy of photon according to Einstein: $E = mc^2 \Rightarrow E = h\nu = \frac{hc}{\lambda} = mc^2$
Momentum of a moving photon	Momentum of moving photon $p = mc = \frac{mc^2}{c} = \frac{E}{c} = \frac{1}{c}\left(\frac{hc}{\lambda}\right) = \frac{h}{\lambda} \Rightarrow P = \frac{h}{\lambda}$
Effective mass of photon	$m = \frac{E}{c^2} = \frac{h\nu}{c^2} = \frac{h}{c\lambda} = \frac{p}{c}$
Relation of photon	As; $Momentum: p \propto m \text{ and } p \propto E$ $\text{and } Energy: E \propto m$ $\text{and Wavelength of wave}: \lambda \propto \frac{1}{p}, \lambda \propto \frac{1}{m}, \lambda \propto \frac{1}{E}$
Wavelength of photon	$\lambda = \frac{h}{p} = \frac{h}{mc} = \frac{hc}{E}$
Charge on photon	*No charge*

Moving Charged particle

Suppose the mass of a particle at rest is m and it is moving with velocity v.

Mass at rest	m
Momentum	$Momentum, p = mv = \sqrt{2mE} \quad E \rightarrow K.E$
Effective/Relativistic mass	$= \frac{m}{\sqrt{1 - \frac{v^2}{c^2}}}$
Kinetic energy	$k.e = \frac{1}{2}mv^2 = \frac{p^2}{2m}$
wavelength	If λ is the wavelength of connected wave to the moving particle, then: $\lambda = \frac{h}{p} = \frac{h}{mv} = h/\sqrt{2mE}$

Charged Particle Accelerated by V-volt

Kinetic energy	he kinetic energy of a charged particle having charge q, mass m, accelerated by V volt, and a velocity v is denoted by: $E = \frac{1}{2}mv^2 = qV$

- The experimental verification which was done by Hertz.
- The photoelectric effect refers to the emission/ejection of electrons from the surface of a metal in response to incident light (or electromagnetic wave).
- The electron ejected due to photoelectric effect is called a photoelectron and is denoted by e^-.
- Current produced as a result of the ejected electrons is called photoelectric current.
- Photoelectric effect proves quantum nature of light.
- Photoelectric effect cannot be explained by the classical wave theory of light. The wave theory is incapable of explaining the first 3 observations of the photoelectric effect.
- Photoelectrons, generally, refer to the free electrons that are in the inter-molecular spaces in the metal.
- Explanation for Photoelectric effect was successfully explained given by Albert Einstein as being the result of light energy being carried in discrete quantized packets. For this excellent work he was honored with the Nobel prize in 1921.
- The law of conservation of energy forms the basis for photoelectric effect.

Threshold Frequency (f_0):

- ✓ The minimum frequency of the incident light or radiation that will produce a photoelectric effect i.e., ejection of photoelectrons from a metal surface is known as threshold frequency for that metal.
- ✓ Its value, though constant for a specific metal, may be different for different metals.
- ✓ If f = frequency of incident photon & f_o = Threshold Frequency Then

(a) If $f < f_o$, there will be no ejection of photoelectron and, therefore, no photoelectric effect.
(b) If $f = f_o$, photoelectrons are just ejected from metal surface, in this case the kinetic energy of electron is zero.
(c) If $f > f_o$, then photoelectrons will come out of the surface along with kinetic energy.

Threshold Wavelength (λ_o):

- ✓ The greatest wavelength of the incident light or radiation for a specified surface for the emission of photoelectrons is known as threshold wavelength $\lambda_o = \frac{c}{f_o}$
- ✓ For wavelengths above this threshold, there will be no photoelectron emission.
- ✓ For λ = wavelength of incident photon, then

(a) If $\lambda < \lambda_o$, then photoelectric effect will take place and ejected electron will posses' kinetic energy.
(b) If $\lambda = \lambda_o$, then just photoelectric effect will take place and kinetic energy of ejected photoelectron will be zero.
(c) If $\lambda > \lambda_o$, there will be no photoelectric effect.

Work Function or Threshold Energy (ϕ):

- ✓ The minimal energy or thermodynamic work that is needed to remove an electron from a conductor/solid body to a point in the vacuum immediately outside the surface of the solid body/conductor is called the work function or threshold energy for the conductor.

$$\phi = h\nu_o = \frac{hc}{\lambda_o}$$

- ✓ Work function is the characteristic of given metal
- ✓ If E = energy of incident photon, then

(i) If $E < \varphi$, no photoelectric effect will take place.
(ii) If $E = \varphi$, just photoelectric effect will take place but the kinetic energy of ejected photoelectron will be zero.
(iii) If $E > \varphi$, photoelectric effect will take place along with possession of the kinetic energy by ejected electron

Laws of Photoelectric Effect

- For a given substance, there is a minimum value of frequency of incident light called threshold frequency below which no photoelectric emission is possible, howsoever, the intensity of incident light may be. It is given by:

$$f_o = \frac{c}{\lambda_o}$$

- The number of photoelectrons emitted per second (i.e. photoelectric current):

$$\text{Photoelectric current} \propto \text{Intensity of incident light}$$

- Current is independent of frequency.
- Provided the frequency above threshold;

$$\text{Maximum Kinetic energy} \propto \text{Frequency}$$

Velocity	$V = \sqrt{\frac{2qV}{m}} = \sqrt{\frac{2E}{m}}$
Momentum	$P = \sqrt{2mE} = \sqrt{2mqV}$
Wavelength	$\lambda = \frac{h}{P} = \frac{h}{\sqrt{2mqV}}$ (Here it is assumed that initial potential given to electron is zero)

Some Important Cases:

1) If the moving charged particle is an electron, then:

$$v_e = \sqrt{\frac{2eV}{m_e}} \quad P_e = \sqrt{2m_e eV} \quad \lambda_e = \frac{h}{\sqrt{2m_e eV}} = \frac{12.27}{\sqrt{V}} A^o$$

2) If the moving charged particle is a proton, then:

$$v_p = \sqrt{\frac{2eV}{m_e}} \quad P_p = \sqrt{2m_p pV} \quad \lambda_e = \frac{h}{\sqrt{2m_p pV}} = \frac{0.286}{\sqrt{V}} A^o$$

3) If the charged particle is an α-particle, then:

$$v_\alpha = \sqrt{\frac{2(2e)V}{m_\alpha}} = \sqrt{\frac{eV}{m_p}} = \frac{1}{\sqrt{2}} v_p.$$

$$P_\alpha = \sqrt{2m_\alpha e_\alpha V} = \sqrt{2 \times 8m_p \times eV} = 2\sqrt{2}p_p$$

$$\lambda_\alpha = \frac{h}{\sqrt{16m_p eV}} = \frac{0.101}{\sqrt{V}} A^o$$

Electron Emission

⇒ Electrons are negatively charged particles. Therefore, though they move about arbitrarily in a conductor at room temperature, they cannot leave the surface of the conductor due to attraction of positively charged particles(protons).

⇒ Therefore, some external energy has to be provided so that the electrons can be ejected from the atoms on the surface of the conductor. To eject the electrons which are just on the surface of the conductor, only minimal energy is required. This minimal energy or thermodynamic work that is needed to remove an electron from a conductor/solid body to a point in the vacuum immediately outside the surface of the solid body/conductor is called the work function (denoted by W) of the conductor. Work function is the property of the metallic surface.

⇒ Heat, light, electric energy etc., can be employed to liberate an electron from a metal surface.

Depending on the source of energy, the following methods are possible:

1) ***Thermionic emission:*** to eject electrons by heating.
2) ***Field emission:*** The emission of electrons induced by an electrostatic field is called field emission.
3) ***Secondary emission:*** Ejection of electrons from a solid that is bombarded by a beam of charged particles (e.g., electrons or ions) is known as secondary emission.
4) ***Photoelectric emission:*** The photoelectric effect refers to the emission/ejection of electrons from the surface of a metal in response to incident light (or electromagnetic wave). This happens when the incident light or electromagnetic wave has greater energy then the work function of the metal. The electrons emitted in this process are called photoelectrons.

Photoelectric effect

⁝≡ The photoelectric effect was discovered by Wilhelm Ludwig Franz Hallwachs in 1888.

Therefore, as far as photoelectricity goes, the photon/particle theory seems ... of the wave theory of light. Modern physicists have reconciled this apparent paradox by postulating the dual nature of light, i.e., light behaves as a wave under some circumstances and like a particle, or photon, under others.

Einstein's Equation of Photoelectric Effect

⇒ Einstein (1905) explained photoelectric effect on the basis of quantum theory.

⇒ According to Einstein, when photons fall on a metal surface, they transfer their energy to the electrons of metal. When the energy of photon is larger than the minimum energy required by the electrons to leave the metal surface, the emission of electrons take place instantaneously.

⇒ He proposed that after absorbing the photon, an electron either leaves the surface or dissipates its energy within the metal in such a short interval that it has almost no chance to absorb second photon.

⇒ The energy supplied to the electrons is used in two ways:

(a) Removes the electron from the surface of metal

(b) Supplies some part of kinetic energy to the photoelectron. Therefore, Einstein's equation of photoelectric effect can be written as:

If v_{max} is the maximum velocity of emitted electrons then by law of conservation of energy

$h\nu = \phi + \frac{1}{2}mv^2$. If f_o: *Threshold frequency* $\therefore \phi_o = hf_o$. So $\Rightarrow h\nu = hf_o + \frac{1}{2}mv_{max}^2$

Einstein's equation explains the following concepts

⇒ The frequency of the radiation/incident light is directly proportional to the kinetic energy of the electrons and the wavelength of radiation/incident light is inversely proportional to the kinetic energy of the electrons.

If f_o is threshold frequency then maximum kinetic energy

$$E_{max} = hf - hf_o \Rightarrow \frac{1}{2}mv_{max}^2 = h(f - f_o)$$

So maximum velocity of photoelectrons:

$$v_{max} = \sqrt{\frac{2h(f - f_o)}{m}}$$

m = mass of electron, f = frequency of incident light, f_o = threshold frequency.

λ_o = threshold wavelength, λ = incident wavelength

$$E_{max} = hc\left(\frac{1}{\lambda} - \frac{1}{\lambda_o}\right) \Rightarrow \frac{1}{2}mv_{max}^2 = hc\left(\frac{1}{\lambda} - \frac{1}{\lambda_o}\right)$$

⇒ If $f = f_o$ or $\lambda = \lambda_o$ then $f = 0$

⇒ $f < f_o$ or $\lambda > \lambda_o \Rightarrow$ No Photo electric effect

⇒ Intensity of the radiation or incident light refers to the number of photons in the light beam. More intensity means a greater number of photons and vice-versa. Intensity has no bearing on the energy of photons. Therefore, intensity of the radiation is increased, the rate of emission increases but there will be no change in kinetic energy of electrons. With increasing number of emitted electrons, value of photoelectric current increases.

Discussion

✓ Value of photoelectric current depends upon following parameters:
(i) Potential difference between electrodes. (ii) Intensity of incident light.

✓ Intensity of Light (I)

(a) It is quantity of light energy falling normally on a uniform surface area in unit time.

$$I = \frac{E}{A.t} \quad t \rightarrow \text{time of exposure}$$

$$E = nh\nu = n\frac{hc}{\lambda} \quad n \rightarrow \text{no of photons}$$

(b) Intensity of light is proportional to saturation current.

(c) For a point source of light, $I_r \propto \frac{1}{r^2}$.

(d) For the Linear source of light $I_r \propto \frac{1}{r}$

r is the distance of the point from the light source.

- However, the relationship between the wavelength and kinetic energy is inversely proportional. With increasing frequency of incident light, the kinetic energy of photoelectron increases but with increasing wavelength it decreases.
- The maximum kinetic energy of the photoelectrons is independent of the intensity of the incident light.
- The process of photoelectric emission is instantaneous, i.e., as soon as the photon of suitable frequency falls on the substance, it emits photoelectrons.
- The photoelectric emission is one-to-one. i.e. for every photon of suitable frequency one electron is emitted.
- Value of threshold frequency or threshold wavelength depends upon photo sensitive nature of metal.

Failure of Wave Theory to Explain Photoelectric Effect

- **Note** - The assumptions of the classical wave theory could not explain some observations of the photoelectric effect. These aspects of the photoelectric effect were later explained by Albert Einstein's photon theory. The failures of the classical wave theory in explaining the photoelectric effect are enumerated below:

1) The wave theory suggests that the intensity of the radiation should have a proportional relationship with the resulting maximum kinetic energy. However, $K.e_{max} = eV_o$ = suggests that it is independent of the intensity of light.
2) According to the wave theory, the photoelectric effect should occur for any intense light, regardless of frequency or wavelength. However, the equation suggests that photo emission is possible only when frequency of incident light is either greater than or equal to the threshold frequency f_o .
3) The wave theory states that there should be a delay on the order of seconds between the radiation's contact with the metal and the initial release of photoelectrons. It was assumed that between the impinging of the light on the surface and the ejection of the photoelectrons, the electron should be "soaking up" energy from the beam until it had accumulated enough energy to escape. However, no detectable time lag has ever been measured.

In reality, due to collision between atoms inside the metal, some energy is lost. Hence kinetic energy emitted by electrons is $k < k_{max}$. Hence the term k_{max} is used for the actual total kinetic energy.

Einstein's Photon Theory

- Albert Einstein worked his way around the limitations of the classical wave theory by explaining that lights exists and travels as tiny packets/bundles called photons. The energy E of a single photon is given by $E = hf$

Applying the photon concept to the photoelectric effect, Einstein wrote:

$$hf = W + K_{max}$$

Discussed below is how Einstein's photon hypothesis overcomes the three objections raised against the wave theory interpretation of the photoelectric effect.

Objection 1: Intensity of the radiation should have a proportional relationship with the resulting maximum kinetic energy. This objection is overcome by Einstein's photon theory because, doubling the light intensity merely doubles the number of photons, thereby doubling the photoelectric current. It does not, however, change the energy of the individual photons.

Objection 2: Photoelectric effect should occur for any intense light, regardless of frequency or wavelength. The existence of a minimum frequency level (in Einstein's photon theory) follows from equation $hf = W + K_{max}$. If K_{max} equals zero, then $hf_o = W$, which implies that the photon's energy will be barely adequate to eject the photoelectron and that there will be no residual energy to manifest as kinetic energy. The quantity W is the work function of the metal/substance. If the frequency f is reduced below f_o , the individual photons, irrespective of how numerous they are (in other words, no matter what the intensity of the incident light/radiation is), will not have enough energy to eject photoelectrons.

Objection 3: There should be a delay on the order of seconds between the radiation's contact with the metal and the initial release of photoelectrons. The absence of a time lag follows from the photon theory because the required energy is supplied in packets/bundles. Unlike in the wave theory, the energy is not spread uniformly over a large area.

$f \propto$ No of ejected electrons	*Experimentally*
$K.E_{max} \propto$ Intensity	$f \propto K.E_{max}$
P.E.E not an instantaneous effect	Intensity $\propto$ Current
	P.E.E is an instantaneous effect

Stopping Potential and Maximum Kinetic Energy

⇒ When the frequency of the light/radiation is greater than the threshold frequency of the metal on which the light is directed, some photoelectrons are emitted from the metal with substantial initial speeds.

⇒ Let us assume that E is the energy of light incident on a metal surface and W (<E) the work function of metal. In this case, as minimum energy is required to extract electrons from the surface, the emitted electrons will have the maximum kinetic energy which is

$$E - W.K_{max} = E - W$$

⇒ As the potential V is increased, the electrons experience greater resistance/repulsion, and consequentially, a smaller number of electrons reach the plate Q. This leads to a decrease in the flow of current in the circuit. At a certain value V_o, the electrons having maximum kinetic energy (K_{max}) also stop flowing and current in the circuit becomes zero.
This is called the stopping potential.

- ✓ In photoelectric cell, when (+) ve voltage is applied on cathode and negative voltage is applied on anode applied, then the magnitude of photoelectric current decreases as the potential difference between the two points (cathode and anode) increases.
- ✓ The stopping potential is the negative potential (V_o) applied to the anode where the current gets reduced to zero or stops flowing in the circuit.
- ✓ When the magnitude of negative potential on anode is greater than or equal to magnitude of stopping potential the current in the circuit becomes zero.
- ✓ If emitted electrons do not reach from cathode to anode then stopping potential is given by:

$$eV_o = \frac{1}{2}mv^2 \text{ or } E_{max} = eV_o\ ; eV_o = h(f - f_o); V_o = \frac{h(f - f_o)}{e}$$

- ✓ Value of stopping potential depends upon frequency of incident light.
- ✓ Stopping potential also depends upon nature of metal (or work function)
- ✓ Stopping potential does not depend upon intensity of light.

Compton's Effect

⇒ According to Compton, "when a beam of X-rays is passed through matter (he uses graphite block, having loosely bound electrons) then the wavelength of scattered X-rays (scattered = the rays which passed through a matter) will be longer than the wavelength of the incident X-rays.

⇒ We can also summarize his saying in way that "*Energy of incident Rays > Scattered Rays*".

⇒ Or *Frequency of incident rays > frequency of Scattered.*

⇒ Or *Momentum of incident rays > Momentum of Scattered.*

⇒ According to Compton the change in wavelength, energy, frequency, momentum of incident rays depends upon the angle on which it strikes the matter. And it is independent of intensity/frequency, energy, wavelength of scattered photon.

⇒ Difference and similarity between Photoelectric effect and Compton's effect:

Photoelectric effect	Compton's effect
Light (photon) is absorbed	Light is not absorbed
Light interact with field of electrons.	=

For explanation of this effect (why it happens) Photon assumed Particle nature of light (Photon theory):

⇒ According to Compton if electron behave like particle then its collision with other particles is similar to the collision between two billiard balls called **elastic collision** (momentum and energy conserved).

He uses conservation of energy and momentum for its explanation.

⇒ ***The incident photon momentum and energy are:***

$$P = \frac{h}{\lambda} \quad and\ E = hf = \frac{hc}{\lambda}$$

⇒ ***The scattered photon momentum and energy are:***

$$P = \frac{h}{\lambda'} \quad and\ E = hf' = \frac{hc}{\lambda'}$$

According to Compton if the collision of photon (x-ray) with matter is elastic, then the photon (ray) will transfer some of its energy and momentum to matter to electron (atoms of the matter).

⇒ ***The relativistic conservation of energy (considered by Compton) is given by:***

$$hf(E_{photon}) = K.E + hf'$$

$$\frac{hc}{\lambda} = K.E + \frac{hc}{\lambda'}$$

$$hf \rightarrow Energy\ of\ incident\ photon$$

$$K.E \rightarrow Kinetic\ energy\ give\ by\ photon\ to\ electron(due\ to\ movement)$$

$$f' \rightarrow frequency\ of\ scattered\ ray$$

⇒ ***The relativistic conservation of momentum considered by Compton is given by:***

$$\vec{P} = \vec{P_o} + \vec{P}'$$

$$\vec{P_o} \rightarrow Momentum\ of\ scattered\ ray$$

$$\vec{P}' \rightarrow Momentum\ of\ recoiling\ electron$$

⇒ Conservation of energy:

$$Energy\ before\ collision = Energy\ after\ collision\ of\ photon$$

Initial energy:

$$hf(energy\ of\ incident\ photon) + m_oc^2(rest\ mass\ energy\ of\ electron)$$

Energy after collision:

$$hf'(Energy\ of\ scattered\ photon) + m_oc^2\ (Rest\ mass) + K.E(k.e\ of\ e\ due\ to\ movemment)$$

$$K.E_{relativistic} = (m - m_o)c^2$$

So;

$$hf + m_oc^2 = hf' + m_oc^2 + K.E$$

$$hf - hf' = (m - m_o)c^2$$

$$\frac{hc}{\lambda} - \frac{hc}{\lambda'} = (m - m_o)c^2 \qquad (1)$$

⇒ Conservation of momentum:

$$Momentum\ before\ collision = Momentum\ after\ collision\ of\ photon$$

By resolving momentum into its components;

y-Component:

$$Initial\ momentum = Final\ momentum$$

Initial momentum:

$$Zero\ along\ y$$

Final momentum:

$$\frac{h}{\lambda}si\theta - Psin\phi(relativistic\ moementum) \qquad \therefore P = \frac{mv}{\sqrt{1 - \frac{v^2}{c^2}}}$$

X-Component:

$$Initial\ momentum = Final\ momentum$$

Initial momentum:

$$\frac{h}{\lambda} + 0$$

Final momentum:

$$\frac{h}{\lambda'}Cos\theta - cos\phi(relativistic\ moementum) \qquad \therefore P = \frac{mv}{\sqrt{1 - \frac{v^2}{c^2}}}$$

By combining all these equation from all conservation, we can derive a special equation for increase in wavelength of scattered photon (X-rays):

$$\Delta\lambda = \lambda' - \lambda = \frac{h}{m_o c}(1 - \cos\theta)$$

$\Delta\lambda \rightarrow$ *Increase in wavelength and is called Compton shift*

Discussion

✓ $if\ \theta = 0° \rightarrow \cos(0) = 1$

For this angle $\Delta\lambda = 0 \Rightarrow$ *so no change in* λ, f *and* E *occur*

$$E = E'$$
$$f = f'$$
$$\lambda = \lambda'$$

✓ $if\ \theta = 90° \rightarrow \cos(90°) = 0$

For this angle $\Delta\lambda = \frac{h}{m_o c} \Rightarrow \lambda - \lambda' = \frac{h}{m_o c} \Rightarrow \lambda' = \lambda + \frac{h}{m_o c} \Rightarrow So\ \lambda' > \lambda$

For this angle $\Delta\lambda = \lambda_c$

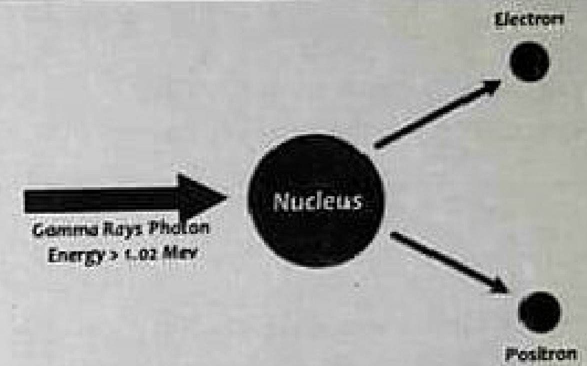
✓ $if\ \theta = 180° \rightarrow \cos(180°) = -1$

$$\Delta\lambda = 2\lambda_c \text{ and so } \lambda' > \lambda$$

For this angle maximum change in wavelength occur

⇒ In classical physics there is no explanation of Compton's effect but Experimental results agree with Compton effect.

Pair Production



⇒ If low energy ($Energy < 0.5Mev$) photon interacts with matter photoelectric effect occurs.

⇒ If high energy ($0.5Mev < Energy < 1.02Mev$) photon (X-rays) interacts with matter Compton effect occurs.

⇒ If we use extremely high energy ($E \geq 1.02Mev$) photon with matter Pair production occurs.

⇒ Here we can use photons of high energy, such as gamma $\gamma - rays$.

⇒ In this case pair of particles produce/generates from high energy gamma rays.

$$if\ Energy \geq 1.02\ Mev \Rightarrow Pair\ of\ electron\ e^- \ and\ Positron\ e^+\ produced$$
$$if\ Energy < 1.02\ Mev \Rightarrow No\ pair\ production$$

⇒ Conservation laws obeyed by Pair production process.

⇒ ***Law of conservation of charge:***

As we know that here two particles name (electron and proton are produced), positron is anti-particle/ Sister particle of electron having same magnitude of charge and mass but the charge on electron is negative and charge on positron is positive, so the net charge comes out to be zero.

⇒ ***Law of conservation of momentum:***

For conservation of momentum the presence of Nucleus is necessary.
The electron and positron move in opposite direction and the nucleus get other momentum and recoils towards back. In this way the momentum conservation becomes fulfill.

⇒ ***Law of conservation of energy:***

$$E = mc^2$$
$$m_{e^-}c^2 = 0.51Mev$$
$$m_{p^+}c^2 = 0.51Mev$$
$$= 2m_e c^2 = 1.02Mev$$

⇒ The overall energy of incident photon (gamma rays) is given by;

$$hf = 2m_e c^2 + K.E(e^-) + K.E(e^+)$$

Annihilation (completely destruction) of matter

⇒ In this process mass completely converted into energy (this is not true according to classical physics).

$$if\ Particle + Antiparticle\ (Mass) \rightarrow (Energy)$$

$$Electron \quad + \quad Positron \quad \rightarrow 2\gamma\ rays$$

⇒ Every matter has its anti-matter (same mass but opposite charge).

⇒ As we know that rest mass energy of photon and positron each is 0.51 Mev, so the total energy of each gamma ray is also 0.51.

⇒ The two-photon produced moves in opposite direction.

PARTICLE AND WAVE NATURE OF ELECTRON

⇒ In 1924, de Broglie proposed that an electron, like light, behave both as a material particle and as a wave.

⇒ This proposal gave birth to a new theory known as wave mechanical theory of matter. According to this theory, the electrons, protons and even atoms,' when in motion, possess wave properties.

⇒ de Broglie derived an expression for calculating the wavelength of the wave associated with the electron; According to Planck's equation;

$$E = h\nu = h\frac{c}{\lambda} \qquad (i)$$

The energy of a photon on the basis of Einstein's mass- energy relationship is;

$$E = mc^2 \qquad (ii)$$

where, c is the velocity of the electron. Equaling both the equations, we get

$$h\frac{c}{\lambda} = mc^2 \Rightarrow \lambda = \frac{h}{mc} = \frac{h}{p}$$

⇒ This equation clearly shows that $\lambda \propto 1/p$.

⇒ Let kinetic energy of the particle of mass 'm' is E;

$$E = \frac{1}{2}mv^2 \Rightarrow 2Em = m^2v^2 \Rightarrow \sqrt{2Em} = mv = p(momentum)$$

$$\lambda = \frac{h}{p} = \frac{h}{\sqrt{2Em}}$$

⇒ Comments: Like electromagnetic waves, moving bodies also exhibit the wave-particle duality and the wave and particle aspects of moving bodies cannot be observed simultaneously. A moving body will exhibit particle behavior if the wavelength of the body is negligible in comparison to its dimension whereas it will exhibit a wave nature if its wavelength is in order of the dimension of body.

MCQ: Determine Broglie wavelengths of

(a) a 46g golf ball with a velocity of 30 m/s and

(b) an electron with a velocity of 10^7 m/s.

Solution: The de-Broglie wavelength of the particle of mass m and moving with velocity v is given by $\lambda = \frac{h}{p} = \frac{h}{mv}$ where h is Planck's constant.

(a) Since v<<c, we can let (effective mass = Rest mass) $m = m_0$.

Hence $\lambda = \frac{h}{mv} = \frac{6.62\ 10^{-34}\ J.s}{(0.04kg)(30m/s)} = 4.8 \times 10^{-34}\ m$

Thus, we see that the wavelength of the golf ball is so negligible compared with its dimensions that we would not be able to observe expect to find any wave aspects in its behavior.

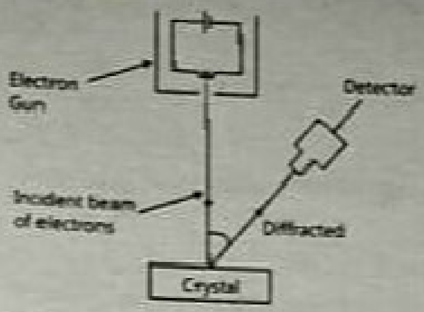
(b) Again v << c, so with $m = m_0 = 9.1 \times 10^{-31}\ kg$

we have $\lambda = \frac{h}{mv} = \frac{6.62\ 10^{-34}\ J.s}{9.1\ 10^{-31} \times 10^7\ (kg\ m/s)} = 7.3 \times 10^{-11}m = 0.73\ A^o$

The dimensions of atoms are comparable with the radius of the hydrogen atom which in reality is $5.93 \times 10^{-11}\ m$. So, it is clear that an electron with a wavelength of 7.3×10^{-11} m would demonstrate a wave behavior. Also, we can see that the wave character of moving electrons is facilitates the understanding atomic structure and behavior.

Davisson and Germer Experiment

⇒ The Davisson–Germer experiment conducted by American physicists Clinton Davisson and Lester Germer confirmed the De Broglie hypothesis which says that the particles of matter such as electrons have wave-like properties.



⇒ Experimental confirmation of De Broglie waves was done by scientist Davisson and Germer by firing slow-moving electrons at a crystalline nickel target. The diffraction pattern of electron beam through the nickel crystal was same as those predicted by Bragg for X-rays.

⇒ Since diffraction is the property of waves, the diffraction of electronic beam confirmed that a wave is connected to moving electron beam.

⇒ The electron gun was used to obtain electrons with different energies. This was done by accelerating the e^- by V volt in the electron gun.

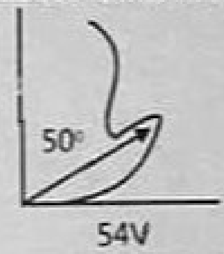
⇒ When these accelerated electrons fall on a crystal, they are diffracted in various directions.

⇒ Electrons were collected by a detector of Faraday cup which was connected to an electrometer.

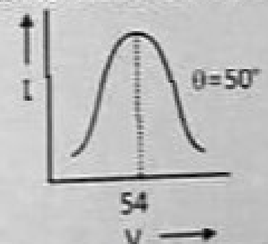
⇒ Electron beams with different energies produced different intensities of diffracted electrons.

⇒ Results of the Davisson–Germer's experiment;

1) Intensity at any angle is proportional to the distance of the curve at that angle from the point of scattering.



2) Intensity is maximum at 54 V potential difference and 50° diffraction angle.



HEISENBERG UNCERTAINTY PRINCIPLE

⇒ Bohr theory considers an electron as a material particle. Its position and momentum can be determined with accuracy. But when an electron is considered in the form of wave as suggested by de Broglie, it is not possible to ascertain simultaneously the exact position and velocity of the electron more precisely at a given instant since the wave is extending throughout a region of space.

⇒ To locate the electron, radiation with extremely short wavelength is required. Radiation that has short wavelength is very energetic in nature. When it strikes the electron, the Impact causes a change in the velocity of the electron.

⇒ Thus, the attempt to locate the electron changes ultimately the momentum of the, electron.

⇒ Photons, with longer wavelengths are less energetic and cause less effect on the momentum of the electron. Because of larger wavelength, such photons are not able to locate the position of an electron precisely.

⇒ In 1927, Werner Heisenberg presented a principle known as Heisenberg uncertainty principle which states: "It is impossible to measure simultaneously the exact position and exact momentum of a body as small as an electron."

⇒ The uncertainty of measurement of position, Ax and the uncertainty of momentum, Δp or Δmv are related by Heisenberg's relationship as:

$$\Delta x.\Delta p(mv) \geq \frac{h}{4\pi}$$

where, h is Planck's constant.

⇒ for an electron of mass m, the product of uncertainty is quite large.

⇒ $\Delta x.\Delta v \rightarrow$ Uncertainty product.

⇒ $if\ \Delta x = 0\ then\ \Delta v = \infty$ and so on-

⇒ In the case of bigger particles (having considerable mass), the value of uncertainty product is negligible. If the position is known quite accurately, i.e. Δx is very small, Av becomes large and vice-versa. Thus, uncertainty principle is important only' in ' the case of smaller moving particles like electrons.

⇒ On the basis of this principle, therefore, Bohr picture of an electron in an atom, which gives a fixed position in a fixed orbit and definite velocity to an electron, is no longer tenable.

⇒ The best we can think of in terms of probability of locating an electron with a probable velocity in a given region of space at a given time.

⇒ The space or it. three-dimensional region round the nucleus where there is maximum probability of finding an electron of a specific energy is called an atomic orbital (See atomic physics).

Same important points and tricks

1) In photoelectric effect, the electrons are assumed to be bound and minimum energy equal to the work function is required to free them.
2) In photoelectric effect, the photon is completely absorbed by the electron.
3) The emitter is a metal plate coated with a photosensitive material.
4) Photoelectrons are emitted almost instantaneously within 10^{-8} second after light source is turned on.
5) The rate of emission of photoelectrons is proportional to the intensity of the light.
6) The kinetic energy of photoelectrons does not depend on the intensity of light.
7) The photoelectrons emitted from the metallic surface have different kinetic energies even when the incident photons have same energy.
8) A photon is not a material particle. It is a quanta (packet) of energy.
9) Light behaves as waves at low frequencies and as particles at high frequencies.
10) A particle having zero rest mass and non-zero energy and momentum must travel with a speed equal to speed of light.
11) Photoelectric effect is due to the particle nature of light.
12) Einstein's photoelectric equation is in accordance with the law of conservation of energy.
13) The work function of metal decreases as the atomic number of elements increases.
14) When temperature increases, work function decreases.
15) Matter waves are associated only with the moving particles.
16) The de Broglie wavelength is independent of charge of the particle.
17) de Broglie suggested that as the light possesses dual nature, same should be true for the particles.
18) Practical observation of matter waves is possible only when the de-Broglie wavelength is of the order of the size of the particles in nature.
19) Matter waves are the probability waves. They are not the electromagnetic waves or mechanical waves.
20) The de Broglie wavelength of electrons in first Bohr orbit of an atom is equal to circumference of orbit.
21) The de Broglie wavelength associated with microscopic particles such as electron, proton, neutron, etc. is of the order of wavelength of X-rays.
22) When a particle exhibits wave nature, it is associated with a wave packet rather than a wave.
23) Electron microscope works on the basis of de Broglie waves.
24) For alkali metals, the threshold frequency lies in the visible region. For zinc, it lies in the ultraviolet region.
25) Infrared radiations cannot eject photoelectrons while X-rays always eject photoelectrons.
26) The amplitude of the matter waves gives the probability of existence of the particle at that point.
27) Matter waves travel as a wave packet with decreasing amplitude on either side of the present position.
28) Out of photon and electron having same de-Broglie wavelength, the total energy of electron is greater than photon and kinetic energy of photon is greater than that of electron.
29) The slope of the graph between stopping potential and frequency gives the ratio of Planck's constant to electronic charge (h/e).
30) The slope of the graph between kinetic energy and frequency gives the Planck's constant (h).

FORMULAS SHEET

1.	Time dilation	$t = \frac{t_o}{\sqrt{1 - \frac{v^2}{c^2}}}$	
2.	Mass variation	$m = \frac{m_o}{\sqrt{1 - \frac{v^2}{c^2}}}$	
3.	Length contraction	$l = l_o\sqrt{1 - \frac{v^2}{c^2}}$	
4.	Einstein's Equation	$E = mc^2$	
5.	Change in mass	$\Delta m = \frac{\Delta E}{c^2}$	
6.	Wein's law	$\lambda_{max} \times T = constant$	
7.	Stefan Boltzmann law	$E = \sigma T^4$	
8.	Energy of photon	$E = hf$	
9.	Momentum of photon	$P = \frac{h}{\lambda}$	$E = pc$
10.	Maximum K.E of photo-electrons	$(K.E)_{max} = V_o e$	$\frac{1}{2}mv_{max}^2 = V_o e$
11.	Photoelectric equation	$hf = \phi + KE_{max} \rightarrow hf = \phi + \frac{1}{2}mv_{max}^2$	$hf - hf_o = KE_{max}$
12.	Compton shift	$\Delta\lambda = \frac{h}{m_o c}(1 - cos\theta)$	
13.	Compton wavelength	$\Delta\lambda = \frac{h}{m_o c}$	
14.	Pair production	$Total\ energy \geq 2m_o c^2$	$hf = 2m_o c^2 + ke_e + ke_{e+}$
15.	Annihilation of matter	$e^+ + e^- \rightarrow \gamma + \gamma$	
16.	De-Broglie hypothesis	$\lambda = \frac{h}{p} = \frac{h}{mv}$	
17.	Davisson and Germier experiment	$\lambda = \frac{h}{\sqrt{2mV_e}}$	
18.	Uncertainty in position	$\Delta x = \lambda$	
19.	Uncertainty in momentum	$\Delta P = \frac{h}{\lambda}$	
20.	Uncertainty principle	$(\Delta x)(\Delta p) = h$	$(\Delta E)(\Delta t) = h$

UNITS

1.	Wien's constant	mk	
2.	Stefan Boltzmann constant	$Wm^{-2}K^{-4}$	
3.	Plank's constant	$J - s$	eV
4.	Work function	J	
5.	Compton wavelength	M	

CONSTANTS

1.	Wein's constant	$2.9 \times 10^{-1}\ mK$
2.	Stefan Boltzmann constant	$5.67 \times 10^{-8}\ Wm^{-2}k^{-4}$
3.	Plank's constant	$6.63 \times 10^{-34}\ J\ sec$
4.	Compton wavelength	$2.43 \times 10^{-12}\ m$